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ELEVENTH QUARTERLY PROGRESS REPORT

Period Covered: November 12, 1978 to February 12, 1979

———

INVESTIGATION OF TEST METHODS,
MATERIAL PROPERTIES, AND PROCESSES
FOR SOLAR CELL ENCAPSULANTS

———

JPL Contract 954527
Project 6072.1

For

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

ENCAPSULATION TASK OF THE LOW-COST
SILICON SOLAR ARRAY PROJECT

The JPL Low-Cost Silicon Solar Array Project is sponsored by the U. S.
Department of Energy and forms part of the Solar Photovoltaic Conversion
Program to initiate a major effort toward the development of low-cost
solar arrays. This work was performed for the Jet Propulsion Laboratory,
California Institute of Technology, by agreement between NASA and DOE.

By

SPRINGBORN LABORATORIES, INC.
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February 1979

CONTENTS

1. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for Task 3 of the Low-Cost Silicon Solar Array project (SSA) funded by DOE. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

During this quarter the technical activities were directed toward the reformulation of ethylene/vinyl acetate copolymer for use as a pottant compound in solar cell module fabrication. Successful formulations were devised that lowered the temperature required for cure and raised the gel content. A major volatile component was also eliminated (acrylate crosslinking agent) which should aid in the production of bubble free laminates.

Adhesive strengths and primers for the bonding of ethylene/vinyl acetate to superstrate and substrate materials was assessed with encouraging results. The incorporation of silane compounds either directly into the polymer as a blend or as a surface coating gave high bond strengths (20 to 30 lbs/in) to glass. The bonds endured 24 hours of boiling water with no delamination. Adhesion to hardboard was also excellent, however, the bonds were severely weakened by water immersion, the failure occurring within the surface of the hardboard. Some type of waterproofing treatment will be required to make hardboard products viable substrates.

A survey of scrim materials was also conducted. These open hole weaves are intended for use as spacers between the cell and substrate to insure thorough cell encapsulation, improve insulation resistance and prevent migration of the pigmented pottant over the cell surface.

2. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of $0.50 per peak watt ($5/ft^2) (1975 dollars), with a projected first year production rate of 500 peak megawatts. This project has a target date of 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirements, and to maximize cost/performance.

The materials cost for encapsulating a 1986 module is targeted at 25 cents per square foot (or $8/meter^2, including frame), with the encapsulation system providing protection to assure outdoor system performance for at least 20 years. Successful system performance is defined as a decay in electrical power output not exceeding 50 percent of original value over this time.

Photovoltaic modules are presently envisioned as being composed of six basic construction elements. These elements are (a) outer covers, (b) structural and transparent superstrate materials, (c) pottants, (d) substrates, (e) back covers, and (f) adhesives. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

Properties being considered are cost, transparency, weatherability and applicability of processing.

This report presents the results of the investigations of the past quarter directed towards the use of ethylene-vinyl acetate (EVA) polymers as the potting compound. Technical activities included the following three areas of effort:

1. Reformulation of the EVA potting compound to improve properties such as cure temperature reduction, lower volatility under vacuum and improved processing techniques.

2. Adhesion studies to assess bond strengths and primer efficiency of the pottant to substrate and superstrate surfaces.

3. The investigation of "scrim" materials to serve as spacers between the cell and substrate.

3. TECHNICAL DISCUSSION

a. EVA - Pottant Reformulation

Ethylene/vinyl acetate (EVA) is a polymer that has been selected for use as a potting compound for solar modules.

After an extensive investigation of transparent plastics, ethylene/vinyl acetate (EVA) was selected from a class of low-cost polymers as being a likely candidate potting compound for use in the fabrication of solar cell arrays. Its selection was based on cost (approximately $0.55 per pound) and an appropriate combination of high optical transparency and easy processing conditions.

This polymer also shows the most promising properties for immediate use with a small amount of modification, but without extensive development efforts. In subsequent studies, Springborn Laboratories proceeded to formulate and compound a useful grade of this material to yield a polymer with the desired properties.*

Table I presents the possibly suitable grades of EVA available on a commercial basis. Only two U.S. suppliers currently exist, DuPont Chemical Co. and United States Industrial Chemicals Co. (USI). The compounds of interest may be selected using transparency as the first criterion. Ninety-one percent transmission values are found for Elvax 150, 250, 4260, 4320, and 4355. Of these the acid modified terpolymers were eliminated due to the melt flow values being too high (Elvax 4320) or too low (Elvax 4260 and 4355) and additionally the cost, being around $0.10/lb. higher than most other grades. The two grades remaining, Elvax 150 was selected over the 250 after running trial extruder runs in the laboratory to assess the processability of the formulated resin. Elvax 150 is a more desirable polymer for the reason of lower extrusion temperatures required due to its higher melt index. The Elvax 250 generated much more heat of shear during the extrusion process which could possibly degrade the peroxide content and lower the shelf life and curing efficiency of the compounded resin.

Two formulations were developed using Elvax 150, a clear compound to cover the sunlit side of the cell and a pigmented white compound to be used as a reflective background behind the cell. These two compounds, designated A8326 and A8320-B, respectively, were published in a previous report and were thoroughly characterized by physical tests, extrusion properties and actual module fabrication. With the background of fabrication experience it became possible to reformulate the EVA to yield a better compound. Some of the properties that needed improvement included:

1. Lower temperature cure.
2. Faster cure, shorter time.
3. Fewer ingredients, if possible.
4. Lowered content of volatile components to reduce bubbling under heat and vacuum.

*Springborn Laboratories, Inc., Ninth Quarterly Progress Report, "Investigation of Test Methods, Material Properties, and Processes for Solar Cell Encapsulants", October 1978.

5. Optimized UV stabilization system.
6. The possible incorporation of compounds such as silane primers to improve the adhesion to substrate or superstrate surfaces.

Conventional formulas for crosslinking EVA frequently employ a co-crosslinking agent, either triallyl cyanurate or SR-350 (trimethylol propane trimethacrylate). It was discovered that with Elvax 150 polymer, better cures are obtained without this agent. A8914-2, clear EVA with no SR-350, gives comparable gel of 90%, and white EVA with no SR-350 went up from 55% to 75% gel content under the same cure conditions.

In addition to improving the speed and degree of cure, the elimination of the SR-350 is advantageous because it removes the large quantity of volatile component that may contribute to bubble formation during the vacuum bag processing step.

Ethylene vinyl acetate copolymer has been compounded in large quantity without any SR-350 crosslinking agent and has also been extruded on a pilot plant scale to yield a sheet of 30 inch width for experimental encapsulation studies. The revised formulations are as follows:

	A8914-2 (clear) parts	A8916-A (white) parts
Elvax 150	100	100
Lupersol 101	1.5	1.5
UV 531	0.25	-
Tinuvin 770	0.10	-
Irganox 1076	0.50	-
Kadox 15	-	5.0
Titanox RF-3	-	2.0
Ferro AM-105	-	0.5

It was noticed during the extrusion process that the screw and barrel temperature rose to about 245°F from the heat of shear. This increase is due to the absence of the SR-350 which plasticized the resin and lowered its melt viscosity. This was not expected to present a problem with the clear formulation; however, it had a significant effect on the white formulation. The white compound extruded with very inadequate mixing of the pigments. The ingredients were poorly dispersed and came out of the extruder in small lumps which could be broken into powder between the fingers. Only translucent streaks of pigment appeared in the body of the polymer. It appears that the SR-350 served as a dispersing agent and a flow modifier for the adequate blending pigment. An approach to solving this problem is to masterbatch the pigment into a small amount of polymer on the mill roll or some other high shear mixing device and then blend it into the final formulation as pellets. This has the advantage of high shear mixing at high temperature without degradation of the peroxide which is blended with the other portion of the resin.

An additional approach to the problem of reducing the heat of shear developed in the extruder is to use a water cooled screw or barrel, thereby permitting the resin to be worked harder without the degradation of the peroxide that occurs with higher (250°F) temperature.

Further investigation was then conducted into the nature of the peroxide curing system. Experiments have shown that the polymer may be cured to a 95 percent gel content with 0.5 phr of Lupersol 101 peroxide, one-third the quantity used in the original formulation. The relationship between gel content and thermal creep resistance was explored. Low levels of peroxide were used to give a range of gel content polymers which were subsequently cured into slabs of 3" x 1-1/2" x 0.5" thickness. These slabs were then hung vertically in a circulating-air oven at 100°C for 120 hours. Thermal deformation became noticeable at 53 percent gel, indicating that the cure system should generate crosslinking in excess of this value.

Other aliphatic peroxides were screened for the curing of EVA at the 0.5 phr level. The only three that worked are listed as follows with the resulting gel contents:

| | Cure | Conditions | | | | |
Peroxide	150°C 5 min.	150°C 10 min.	150°C 20 min.	135°C 5 min.	135°C 10 min.	135°C 20 min.
Lupersol 101	0%	0%	92.9%	0%	0%	0.4%
Lupersol 231	91.5%	91.9%	92.7%	0%	79.8%	92.9%
Lupersol 220-D50	92.6%	93.2%	82.8%	0%	0%	84.6%

No curing occurred below a temperature of 120°C at any length of time.

The results indicate that as little as 5 minutes cure time at 150°C may be feasible using other peroxides, or that the usual 20 minutes cure time may be used at a temperature of only 135°C. Lupersol 231 is probably the best suited peroxide for EVA, if it proves to be compatible with the other additives, especially the antioxidants. Chemically, Lupersol 231 is 1,1-bis(t-Butyl peroxy) 3,3,5-trimethyl cyclohexane.

The results of a more extensive investigation are shown in Table III. Lupersol 101 and Lupersol 231 were compared for cure efficiency by gel content in a typical EVA formulation incorporating UV stabilizers and an antioxidant. Both Elvax 150 and 250 were used in this experiment to further compare the usefulness of the resins. The results indicate that Elvax 150 is much more successfully cured than the 250 and that Lupersol 231 appears to be the peroxide of choice for this application. Higher gel contents, lower concentrations, wider range of cure temperatures and shorter cure times all make Lupersol 231 the most desirable curing agent. The lower temperature of cure is also advantageous for two reasons: the modules may be thermally equilibrated faster and the peroxide residues are more easily destroyed by additional heating to minimize possible UV sensitization. Subsequent formulations will use Lupersol 231 instead of 101.

A recurring problem in module fabrication is that of bubble formation in the pottant layer surrounding the cell. These problems are for the most part alleviated by correct control of vacuum during the encapsulation/curing process, but a certain rate of rejects is still encountered.

The source of the bubbles is thought to be at least in part due to volatile components present in the pottant and an attempt was made to compare compounds and formulations of interest. The starting approach to this problem was to measure the escape of volatiles (weight loss) during oven heating at two times and two temperatures. Table IV records the weight losses found for Elvax 150, 250, Polyvinyl butyral, and two pottant formulas. Polyvinyl butyral was included as a control material because it does not present any problem with bubbles during a similar lamination process (safety glass manufacture). Surprisingly, PVB had the largest weight loss of any of the specimens although no bubbles appeared in the heated sample. All the EVA formulations developed bubbles, even the uncompounded virgin resins. Some other comparative method will have to be developed to examine this problem.

b. Adhesion Studies

Adhesives, primers or some other mechanism are necessary for the high reliability bonding of the assembly components to one another in order to insure the structural integrity and long life performance of the module. The adhesion between the pottant and other components, i.e., substrate, superstrate and outer cover, was investigated in the past quarter and some encouraging results were obtained with the use of primers. An advantage is presented by the use of ethylene/vinyl acetate copolymers as pottants because these materials have adhesive properties to begin with and are widely used in the industry in the formulation of hot-melt adhesives.

Primers were investigated instead of adhesives in order to generate the highly dependable bonds needed between the components. Primers were selected for initial investigation because of distinct advantages over adhesives they present, which are as follows:

a. Cost effectiveness, only a very thin layer is required to create an effective bond.

b. Primers are frequently 100% active systems requiring no drying times to remove solvent vehicle.

c. High transparency, such a thin layer is used that no loss of transmission is encountered in the optical path.

d. Adhesion usually occurs by chemical bonding, giving a high dependability bond.

e. Easily applicable to surfaces by dip or spray process or any technique for low viscosity fluids.

f. May be active by blending into the pottant before the encapsulation step and eliminate the priming operation.

g. Rapid bonding...no lengthy cure cycle required.

Table VI (pp.17) shows the results of adhesion bond strength evaluations of materials and primers investigated to date. The test specimens were prepared in a manner similar to that which would be encountered in actual module fabrication. All substrate/superstrate specimens were evaluated by ASTM method D-903 for the peel or stripping strength of laminates, in which the polymer layer is pulled back off the substrate at a 180 degree angle. For flexible specimens, such as polymer bonded outer cover materials, ASTM method D-1876 ("T"-Peel) was employed. All values are reported as pounds of stress per inch of width of bond line. Specimens showing high control values were further tested after water immersion for two weeks and exposure to boiling water for periods of two hours and twenty four hours. According to one researcher, 24 hours of boiling water is approximately equivalent to one year of water exposure[a].

In substrate module constructions, pigmented white or possibly clear EVA is to be bonded to Super-Dorlux hardboard. The bond strengths were found to be satisfactory after molding and curing without the use of any primers or adhesion promoters. Molding plain stabilized EVA to the surface of Super-Dorlux gave a good bond that failed by cohesion in the polymer at a break strength of 24 lbs per inch with no surface treatment. Adhesion of the white pigmented compound under the same conditions did not perform quite as well, producing bond strengths averaging 12.3 lbs per inch of width.

Sanding the substrate first does not appear to improve the adhesion much, probably due to a loosening of the immediate surface (A8912-4). Drying the Dorlux before bonding (A8912-7) resulted in greatly reduced adhesion, with an average bond strength of 4 lbs/in. of width. The best adhesion with white EVA was found when the surface was primed with SS-4179 silane (or A8330B silane). This treatment resulted in cohesive failure at 24 lbs/in.

Primers combined internally with the polymer were not quite as effective in promoting bond strength. One part per hundred resin of mixed silane (A-8121-2) in the polymer formulation gave an acceptable strength of 17.1 lbs/in. When these two components are forcibly separated, the failure occurs principally within the immediate surface of the hardboard and the EVA pulls away with a thin covering of Dorlux attached to it. Soaking in hot (60°C) toluene for several hours followed by forced separation leaves a layer of strongly adhering EVA on the surface of the hardboard that appears to be chemically bonded.

Surface delamination within the hardboard appears to be the biggest potential problem with this material.

Water immersion of the hardboard specimens was disasterous, in most cases. Only two specimens, white EVA to sanded Dorlux and EVA with internally compounded primer (specimen A8930A), retained good bond strengths of 12 to 14 lbs/inch. All specimens that failed (by peeling) revealed the failure to be in the immediate surface of the hardboard and the polymer pulled away with a covering of wood fibers on the surface. Boiling water immersion reduced all the bond strengths to an average value of 2 lbs/inch. These experiments indicate that a waterproofing treatment of some variety is essential for long bond life with hardboard products.

a. Edwin P. Plueddemann, Dow Corning Corporation, private communication.

Adhesion to glass does not occur as readily as to hardboard and the use of primers is absolutely necessary to obtain any peel strength at all. The EVA formulation molded and cured directly over the glass has essentially no adhesion (0.3 lbs/in). The approach to bonding glass was essentially the same as for hardboard, using primers both within the polymer and applied to the surface, the sides were differentiated, however. Soda-lime glass is prepared by a process of floating the melt of a bath of molten tin. This results in the glass having two sides, an air side and a tin side, which may give very different adhesive characteristics. The sides were identified with the use of a ultraviolet light (short-wave - 256 nm) which causes the tin side to fluoresce with a pale yellow glow. The air sides were labeled A or 1 depending on which lot of glass was being tested.

Excellent results were obtained with both techniques. For surface applied primer, the most effective treatment was found with A8330-B (Table V). In use, this primer is swabbed onto the surface of glass that has been precleaned with detergent, acetone and rinsed in distilled water. The coating weight (wet) is approximately 0.5 grams or .001 lbs per square foot. After an air dry period of half an hour at ambient temperature the glass is ready for lamination.

A8330B gave a control value of 21.9 lbs/in and did not appear to be affected by immersion in either room temperature or boiling water. Two weeks water immersion at room temperature gave a bond strength of 23.5 lbs/in (average) and 24 hours in boiling water only reduced the bond to 17.5 lbs/in. In all the specimens the bond was broken by cohesive failure in the polymer, marked by a (b) next to the break strength in Table VI.

Internally blended primers (one part per hundred resin) also gave good results, the best overall A8921-2 primer. Control values were found to average 23 lbs/in. and immersion in boiling water for 24 hours gave a fifty percent reduction to 11 lbs/in. All specimens also failed by cohesion in the polymer. Only in one case did a significant difference appear between the air side and the tin side; internally blended SS-4179 gave significantly higher bond strengths on the tin side.

Of the formulations and techniques tried with glass, the best on an overall performance basis are surface applied A8330-B and internally blended A8921-2. Both these formulations are equally effective on both sides, and give control bond strengths of 20-30 lbs/in. After 24 hours in boiling water the bond is still intact at 17.5 lbs/in (A8330B). These two formulations are also free of the wide variation in values found for many other primers tested.

A few experiments were tried in bonding the EVA pottant to copper and aluminum foil (a potential back over material) but without success. With or without primers no bond strength of any value has been recorded. Bonding the resin to outer cover materials produced variable results. The bond strength to Korad 201-R film gave variable values ranging from 1 to 17 lbs/in. for the water immersion conditions and a less variable and rather low 2.3 lbs/in. control value. Tedlar UT gave a control strength of 13.2 lbs/in. and had less variation in the water immersion specimens. No primers or any other treatment was used with these two films, the bond strengths resulting from free radical crosslinking during the cure of the EVA. The cause of the variation in bond efficiency is not know, however, it is suspected to be a result of surface condition. Perhaps a standardized cleansing procedure of some variety or an appropriate primer will solve the problem.

c. Scrim Materials

A scrim is defined as a cloth of very open weave such that holes or "cells" of a specific size are present throughout the body of the weave. This material is being investigated for use as a construction component in solar modules in which it would serve as a spacer between the cell and some other component (substrate or back cover). The reasons for its use are as follows:

   a. The scrim would provide for a fixed distance between the cell and substrate, insuring a complete encapsulation in the pottant, and providing stress relief.

   b. The scrim material placed behind the cells in the superstrate design would serve to maintain the insulation resistance between cell and back cover (especially if the cover is aluminum foil).

   c. The scrim serves to prevent the overlap of pigmented white EVA over the cell surface during the melt stage in vacuum bag fabrication. This eliminates the necessity of using an additional piece of clear EVA behind the cell.

   d. The scrim provides air channels between the polymer layers that aid in evacuation during the vacuum bag process.

A table of potentially useful low cost scrims appears on page 18. Selected scrims of several geometries and compositions were evaluated by fabrication into one cell modules. Four scrims and one glass cloth were used;

   a. Bayex, QX 8410/F-14, 10 mil, polyester
   b. Apex mills, Duralon S-50, 8 mil, nylon
   c. Apex Mills, Alto, 5 mil, nylon
   d. Window screen, 12 mil polyester
   e. General purpose glass cloth, 8 mil, glass

All products were useful in helping to retard the flow of pigmented EVA to some degree, the best being the glass cloth due to its small hole size. Air entrapment in the cells of the weave was a problem in some of the modules, those using monofilament weaves.

It is strongly suspected that multiple air channels along the fiber of the scrim or cloth are required for proper evacuation of the module during the fusion process. Large weaves of single filament materials invariably trapped air in the cells and particularly in the center of the module. Glass cloth is superior in this respect, presenting the least difficulty with air entrapment and the most efficient evacuation. Glass cloth is also sufficiently white and reflective that it may be possible to eliminate the pigmented EVA if the replacement is determined to be cost effective.

The scrim addition is expected to result in a module cost-add on in the order of $0.015 to $0.025 per square foot.

Due to the success with glass cloth, experiments will continue to determine its usefulness. A wide variety are available, the largest supplier being Burlington Glass Fabric Company, Rockleigh, New Jersey. Samples have been ordered and will be evaluated for cost/performance. The cost is expected to be in the range of .04 to .06$/ft^2.

Currently, the cost of pigmented EVA, in the thickness used, is approximately $0.042 per square foot.

4. FUTURE WORK

Plans for the next quarter will include the following technical activities:

1. An investigation of compounding an adhesion promoting silane primer directly into the EVA potting formulation prior to the extrusion stage.

2. The development and verification of EVA formulas employing Lupersol 231 as the peroxide curing agent.

3. A process for adequately blending the zinc oxide pigment and stabilizers into the EVA by masterbatching or some other technique to yield a white extruded film to function as the reflective background in solar modules.

4. Corrosion testing to determine the degree of protection afforded metal components by EVA encapsulation.

5. The evaluation of EPDM (ethylene/propylene-diene monomer) elastomer as an alternative to EVA as a solar module pottant. Formulation, compounding, extrusion and module construction will be investigated to assess the usefulness of this polymer.

6. Investigations of thermal oxidative stability and selection of an antioxidant optimized for use with EVA.

7. The results of RS-4 fluorescent sunlamp exposure of EVA compounds and protective coatings.

8. The further investigation of glass cloth as a cell spacer, evacuation aid and a possible replacement for pigmented EVA in solar module construction.

TABLE I

Ethylene - Vinyl Acetate Copolymer Survey

Compound	Vinyl Acetate %	Density (g/cc)	Tensile @ Break [2] (psi)	Elongation [2] @ Break (%)	Cost ($/lb.)
EY 901-25	40	0.962	1200	700	$0.64
UE 654-35	33	0.954	660	870	$0.645
UE 638-35	31	0.954	720	960	$0.635
UE 646-04	28	0.949	1,100	770	$0.615
Elvax 150	33	0.957	850	1,050	$0.575
Elvax 240	28	0.951	1,050	900	$0.545
Elvax 250	28	0.951	1,400	950	$0.545
Elvax 260	28	0.955	2,800	1,000	$0.545
Elvax 420	18	0.937	950	700	$0.545
Elvax 350	25	0.948	1,600	900	$0.505
Elvax 4260	28	0.955	2,700	1,000	$0.675
Elvax 4320	25	0.947	750	900	$0.635
Elvax 4355	25	0.952	2,800	1,000	$0.665

(1) Total integrated transmission, solar normalized, 350 - 800nm.

(2) ASTM Test D638; Type IV Specimen.

(3) Melt index figures obtained from ASTM Test D1238 E.

(4) Cost values listed for maximum quantity of material (4-79).

TABLE I (Continued)

Ethylene - Vinyl Acetate Copolymer Survey

Compound	Manufacturer	Composition	UV T%	Vis T% (1)	Refractive Index n_d	Average (3) (g/10 min) Equivalent Melt Index
EY 901-25	USI	EVA	74	86	-	7.5
UE 654-35	USI	EVA	78	84	-	48.0
UE 638-35	USI	EVA	77	86	-	24.0
UE 646-04	USI	EVA	77	85	-	25.0
Elvax 150	DuPont	EVA	73	91	1.482	43
Elvax 240	DuPont	EVA	66	89	1.485	43
Elvax 250	DuPont	EVA	68	91	1.485	25
Elvax 260	DuPont	EVA	68	86	1.485	6
Elvax 420	DuPont	EVA	61	82	1.492	151
Elvax 350	DuPont	EVA	73	87	1.489	19
Elvax 4260	DuPont	EVA/Acid Ter.	67	87	1.485	6.0
Elvax 4320	DuPont	EVA/Acid Ter.	67	91	1.486	150
Elvax 4355	DuPont	EVA/Acid Ter.	67	91	1.482	6.0

(1) Total integrated transmission, solar normalized, 350 - 800nm.

(2) ASTM Test D638; Type IV Specimen.

(3) Melt index figures obtained from ASTM Test D1238 E.

(4) Cost values listed for maximum quantity of material (4-79).

TABLE II

INITIAL EVA FORMULATIONS[a].

Compound	Function	(1) A8322 (Parts)	(2) A8326 (Parts)	(3) A8320-B (Parts)
Elvax 150	Resin	100	100	100
Sartomer SR-350	Crosslinker	3.0	3.0	3.0
Lupersol 101	Initiator	1.5	1.5	1.5
UV-531	UV absorber	-	0.25	-
Tinuvin 770	UV synergist	-	0.10	-
Irganox 1076	Antioxidant	-	0.50	-
Kadox 15 (ZnO)	Pigment	-	-	5.0
Titanox RF-3 (TiO_2)	Pigment	-	-	2.0
Ferro AM-105	Stabilizer	-	-	0.5

(1) Clear, unstabilized

(2) Clear, stabilized

(3) White

a. As published in "Investigations of Test Methods, Material Properties, and Processes for Solar Cell Encapsulants" Ninth Quarterly Progress Report, Springborn Laboratories, Inc., October 1978.

TABLE III

PEROXIDE CURE VERSUS GEL CONTENT

ELVAX 150

A8937 A -	A	B	C	D	E	F
Elvax 150	100	100	100	100	100	100
Lupersol 101	1.5	1.0	0.75	-	-	-
Lupersol 231	-	-	-	1.5	1.0	0.75
Tinuvin 770	0.1	0.1	0.1	0.1	0.1	0.1
UV-531	0.3	0.3	0.3	0.3	0.3	0.3
Irganox 1076	0.2	0.2	0.2	0.2	0.2	0.2
150 C/20 min Gel, %	89.9%	86.4%	86.6%	91.9%	91.4%	88.7%
135 C/20 min Gel, %	-	-	-	90.8%	88.2%	85.6%
A8937 B -		ELVAX 250				
Elvax 250	100	100	100	100	100	100
Lupersol	1.5	1.0	0.75	-	-	-
Lupersol 231	-	-	-	1.5	1.0	0.75
Tinuvin 770	0.1	0.1	0.1	0.1	0.1	0.1
UV-531	0.3	0.3	0.3	0.3	0.3	0.3
Irganox 1076	0.2	0.2	0.2	0.2	0.2	0.2
150 C/20 min Gel, %	85.6%	84.6%	0	86%	88.9%	87.4%
135 C/20 min Gel, %	-	-	-	82.8%	85.1%	0

TABLE IV

Pottant Degassing Experiment
Weight Loss (%)

| | 100°C | | 150°C | |
	1 Hour	5 Hours	1 Hour	5 Hours
Elvax 150	.066	.07	.105	.143
Elvax 250	.10	.145	.157	.256
PVB (SR-10)	.58	.98	2.05	3.84
A8914 (EVA, clear, stabilized) (No SR-350)	.279	.523	.516	1.06
A8937A-D (Clear, stabilized) (Lupersol 231)	.185	.42	.48	.99

TABLE V

PRIMER FORMULATIONS

a. SS-4179   Proprietary formulation, General Electric Co.

*b. A8921-2   A mixture of Dow Corning silane primers;

           Z6030 silane..........9 parts

           Z6020 silane..........1 part

c. A8330 B   Hydrolyzed Dow Corning Z-6030 primer;

           Z-6030.................49.8%

           Methanol..............39.8%

           Water.................9.9%

           Acetic acid...........0.39%

           Mix and heat to reflex for one hour or permit to
           stand at room temperature for 24 hours before using.

*Should be used within one month period of time after mixing and kept under refrigeration when not in use.

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TABLE VI

ADHESIVE BOND STRENGTH EVALUATION
Average Bond Strength by ASTM D903 or ASTM D1876
(Pounds per inch of Width)

Notebook No.	Materials	Primer	A Control	B Water Immersion 2 Weeks	C Boiling Water 2 Hrs.	D Boiling Water 24 Hrs.
A8912-2	Dorlux, clear EVA	None	(b) 24	7.9	1.6	2.5
A8912-3	Dorlux, white EVA	None	12.3	4.8	1.4	2.6
A8912-4	Dorlux sanded, white EVA	None	11.9	12.3	3.1	0
A8912-5	Dorlux, white EVA	SS4179	(b) 24	variable 0 - 13	1.5	2.7
A8912-6	Dorlux, white EVA	A8330B	(b) 23.5	7.9	1.6	1.7
A8912-7	Dorlux, vac. dried, white EVA	None	4.02	-	-	-
A8913-1	Glass A, clear EVA	None	1.84	-	-	-
A8913-6	Glass B, clear EVA	None	4.51	-	-	-
A8913-2	Glass A, clear EVA	SS4179	(b) 21.5	5.6	2.2	13.8
A8913-3	Glass B, clear EVA	SS4179	(b) 18.5	5.7	2.5	(b)Broken
A8913-4	Glass A, clear EVA	A8330B	(b) 21.9	(b) 23.5	(b) 30.9	(b) 17.5
A8913-5	Glass B, clear EVA	A8330B	(b) 20.8	(b) 27.9	(b) 25	9.6
A8928-1	Korad 201R, clear EVA	None	2.3	variable 1 - 17	variable 1 - 16	variable 1 - 14
A8928-2	Tedlar UT, clear EVA	None	13.2	variable 0 - 29	10	10
A8928-3	Aluminum foil, clear EVA	Z6030W	(a)	-	-	-
	Copper foil, clear EVA	A8921-1	(a)	-	-	-
	Aluminum foil, clear EVA	None	(a)	0	-	-
A8930 B	Dorlux, wht. EVA + SS4179	Internal	10.5	8.1	2.2	2.5
A8930 A	Dorlux, wht. EVA + A8921-2	Internal	17.7	14.6	3.5	2.9
A8929-D2	Glass, clr. EVA + SS4179	Internal	Appx. 30	variable 4 - 20	(b) 25	(b)9.7
A8929-C2	Glass, clr. EVA + A8921-2	Internal	(b) 23	(b) 21	(b) 30	(b) 11
A8929-D1	Glass, clr. EVA + SS4179	Internal	9.9	3.5	2.3	2.2
A8929-C1	Glass, clr. EVA + A8921-2	Internal	(b) 32	(b) 24	10	10.5

(a) Delaminated, no strength.   (b) Cohesive failure in polymer.

SCRIM MATERIAL SURVEY

Manufacturer	Product Code	Material	Cell Size (Mils x Mils)	Weight (9/Yd^2)	Scrim Thickness (Mil)	Cell Type	Cost ($/Yd^2)	Cost $/ft^2)
Burlington Glass Fabrics	191	Glass Fibers	50 x 100	46.8	5	. SQ	$.34	$.038
	1562	Glass Fibers	33 x 63	51.1	4.5	SQ	$.24	$.027
	1620	Glass Fibers	50 x 50	45.5	4	SQ	$.15	$.017
	1621	Glass Fibers	33 x 71	67.0	6.2	SQ	$.23	$.025
	1658	Glass Fibers	50 x 100	51.1	4	SQ	$.12	$.013
	1659	Glass Fibers	50 x 100	46.5	4.7	SQ	$.13	$.014
Bay Mills (Bayex)	Qx2111/F-14	Polyester	500 x 1000	15.3	∼10	SQ	$.05	$.005
	Qx8410/F-14	Polyester	12 x 125	65.3	∼10	SQ	$.20	$.022
	GCD1120/A	Polyester	2000 x 1000	5.1	∼ 6	SQ	$.032	$.003
Apex Mills Corp.	Alto	Nylon	50 x 50	9.8	∼ 5	Rhombic	$.25	$.028
	Duralon 30	Nylon	125 x 125	40.7	∼12	Rhombic	$.38	$.042
	Duralon S50	Nylon	63 x 63	34.3	∼ 8	SQ	$.37	$.041
	D1	Nylon	438 x 438	39.9	∼14	Hexagonal	$.42	$.047
	727	Nylon	34 x 34	15.1	∼ 5	Rhombic	$.36	$.04

TABLE VII